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LANDSCAPE STRUCTURE (PATCH PATTERN) OF THE JORKA RIVER CATCHMENT (MASURIAN LAKELAND, POLAND): ANALYSIS OF AIR PHOTOS

ABSTRACT: The objective of the study was to identify components of the landscape of a selected lakeland catchment basin (river Jorka catchment, Masurian Lakeland, Poland), to assess their size and distribution with respect to their cover and use, and to evaluate their role as barriers to nutrient inflow into lakes. Aerial photographs (1:10 000) were applied to identify the use and cover of catchment. Vertical black and white photographs were recorded on negative infrared in 1997 and 1998. The air photos and topographical maps (1:10 000, 1:25 000) were used to identify objects (landscape patches) that differed with respect to their function as barriers to nutrients. Each landscape patch was allocated to one of the eight categories of land cover and use: crop fields, forests (forests on mineral soils, oak-hornbeam forests, mixed coniferous forests), meadows and pastures, wasteland (permanently or temporarily excluded from agricultural use), lakes, wet forests (forests on hydrogenic soils, alder swamps, riparian carrs, and shrubberies), other wetlands (open wetlands, mid-field bodies of water), and built-up land. The identified objects were assigned to three categories with respect to their function as barriers: highly effective barriers (forested and non-forest wetlands, and lakes – 6% of Jorka river catchment); moderate effective barriers (forest, meadows and pastures, wasteland – 42%); and with no barrier function (arable land, built-up land – residential and industrial, tourist objects, etc. – 52%).

KEY WORDS: landscape structure, patch pattern, analysis of air photos

1. INTRODUCTION

The application of air photo interpretation to the analysis of spatial diversity of landscape is very useful in the study of lakeland regions as they represent the mosaics of patches. The mosaic character of a lakeland area is a result of the diversified relief (numerous hills and depressions), natural land cover and land use of the area, involving the crop fields interspersed with wasteland, forest fragments, and also with wetlands, areas without outflow, and lakes (Hillbricht-Ilkowska 1981, Dąbrowska-Prot and Łuczak 1995, Hillbricht-Ilkowska 1999). A landscape consists of a variety of habitats that interact with one another, both natural and human transformed which consists a mosaic of patches interrelated to various degrees (Forman and Godron 1986, Moldan and Černy 1994). Interspersed landscape patches differently used form a mosaic landscape typical also for the Masurian Lakeland. The configuration of landscape patches, their size, way of management, and distance from water bodies determine the rate and amount of nutrient runoff. It depends, for example, on the land use, distribution and size of crop fields, presence of meadows, forests, and wetlands. Agricultural and urban areas are generally sources of nitrogen and phosphorus loadings (Hillbricht-Ilkowska *et al.* 1995, Carpenter *et al.* 1998, Hillbricht-Ilkowska 1999) while forests, meadows, and wetlands, are considered as barriers and filters (Rekolainen 1989, Burt *et al.* 1993, Tiessen 1995, Hakala 1998). The protection of wetlands and their restoration (Kruk 1990, Mitsch 1992, Weller and Wang 1996, Haycock *et al.* 1997) and also landscape management, including the size and distribution of crop fields and wasteland, may restrict nitrogen and phosphorus loading. The function of a barrier to nutrient loading can be performed by a mosaic of landscape patches whose diversified spatial structure, including its use and cover, can minimize nitrogen and phosphorus loading to lakes (Hillbricht-Ilkowska 1995).

Identification of the spatial structure of a landscape is necessary in further studies of its functioning (Lillesand and Kiefer 1994). Air photos enable analyses of large areas in a short time, and both the whole area and fragments of it can be analysed. Air photos register the landscape and its heterogeneity in the form of patches, lines and points (Mozgawa 1995) corresponding to natural elements performing specific functions in the landscape (Forman and Gordon 1986). In the patchy and hilly landscape of the Masurian Lakeland, aerial photographs are most suitable for remote sensing of the environment and its variation. The photointerpretation is based on the assumption that geometrical structures (patches, lines and points) seen on the photos have a unique ecological meaning related with landscape structure and function, and that landscape patch is a structural unit of the landscape (Mozgawa 1995). This method makes possible not only the identification of landscape patches, but also the estimation of their mean size, shape, length of the boundary line, or interrelationships (Mozgawa 1994, 1995). In this way, it is possible to distinguish components important to water protection: that represent effective barriers to nitrogen and phosphorus (wetlands), moderately effective barriers (forests, meadows and pastures), or areas of no importance as barriers (built-up land, roads, etc.) (Mozgawa 1994, 1995). When analysing air photos, it is possible to estimate the mean patch size, length of the boundaries between patches, and to calculate indices describing a patchy landscape (Mozgawa 1994, 1995, Hillbricht-Ilkowska 1999).

The objective of the study was to identify components of the landscape of a selected lakeland catchment basin, to assess their size and distribution with respect to their cover and use, and to evaluate their role as barriers to nutrient inflow into lakes.

2. MATERIAL AND METHODS

The studies were performed on the area of river Jorka lake system on Masurian Lakeland (Fig. 1). Detailed description of the study area is presented in Hillbricht-Ilkowska (2002) and Rybak (2002).

Aerial photographs were applied to identify the use and cover of the Jorka river catchment basin (~65 km^2). Vertical black and white photographs were recorded on negative infrared Kodak Aerographic IR type 2424, in August 1997 and May 1998, along north-south flight lines and a flying height above the ground of 2000 m. The surface area covered with the photos was 103 km^2. Original negatives were used for making diapositives with the overlap of 65% along the flight line and the tranverse overlap of 30%. Enlargements were made on photographic print paper at a scale of 1:10 000, projecting the photos on components of a topographical map.

Moreover, air photos in normal colours were taken to assist in the data analysis.

Topographical maps at scales of 1:10 000 and 1:25 000 (national co-ordinate system 1965) and catastral maps were used to assist in the photo processing and interpretation.

Air photos were scanned at a resolution of 300 dpi. Then geometric distortions produced during image acquisition were eliminated and the photos were projected on the co-ordinate system. The photos were projected on a topographical map (scales 1:10 000 and 1:25 000) by using ground control points. Topographical co-ordinates in the co-ordinate system 1965 were assigned to the points and, after localization on the photos, their photocoordinates were determined. A mathematical relationship was found between the co-ordinate system of the photos and the co-ordinate system of the map (Widacki 1997). The obtained photos had features of a map.

Then topographical maps were converted into digital maps to identify on the photographs objects (landscape patches) that differed with respect to their function as barriers to nutrients. Topographical maps and field -check data were used to identify objects on the photos. Reading and interpretation of air photos were based on features such as photo tone, photo structure (size and shape of objects), and photo texture (spatial configuration of objects) (Ciołkosz *et al.* 1978, Avery and Berlin 1992, Richling 1993). The photointerpretation was used to discern objects, that is, landscape patches that could function as barriers to nutrients. It was assumed that each category formed a uniform functional patch. The patches discerned were not smaller than 10 m × 10 m.

Each landscape patch was allocated to one of the eight categories of land cover and use (Table 1): crop fields, forests (forests on mineral soils, oak-hornbeam forests, mixed coniferous forests), meadows and pastures, wasteland (permanently or temporarily excluded from agricultural use), lakes, forested wetlands (forests on hydrogenic soils, alder swamps, riparian carrs, and shrubberies), other wetlands (non-forested wetlands – open wetlands, mid-field bodies of water), and built-up land.

Table 1. Categories of land use and cover and their barrier function in the Jorka river catchment (Mozgawa 1994)

Land use category	Barrier function
Crop fields	0
Dry forest	+
Meadows and pastures	+
Wasteland	+
Forested wetlands	++
Other wetlands (non-forested)	++
Built-up land	0

0 – no barrier function,
+ – moderate effective barrier areas,
++ – highly effective barrier areas.

The identified objects were assigned to three categories with respect to their function as barriers (Mozgawa 1994, 1995): highly effective barriers (forested and non-forest wetlands, and lakes); moderate effective barriers (meadows and pastures, wasteland); and with no barrier function (arable land, built-up land – residential and industrial, tourist objects, etc.). The above classification was suggested by Mozgawa (1994, 1995) and Hillbricht-Ilkowska *et al.* (1995). The barrier potential of each patch was evaluated considering the study results of Rekolainen (1989), Mitsch (1992), Burt *et al.* (1993), Tiessen (1995), Weller and Wang (1996), Haycock *et al.* (1997).

Boundaries of the Jorka river catchment and the subcatchments of lakes (lakes Majcz Wielki, Inulec, Głębokie, Zełwążek and Jorzec) were delineated from topographical maps (Fig.1). The surface areas and boundaries of the whole catchment and individual subcatchments were measured. Also the length of the lake-catchment contact line was measured. An index of the spatial structure of the landscape was calculated, that is, the percentage of different landscape patch categories in the catchment, and the degree of landscape patchiness expressed as the number of patches of each category per 1 km^2 of the catchment (Mozgawa 1995).

3. RESULTS

The Jorka river basin covers an area of 6300 ha. The river flows through 5 lakes: Majcz Wielki (170 ha), Inulec (153 ha), Głębokie (57 ha), Zełwążek (12 ha), and Jorzec (160 ha) (Fig. 1). It is subjected to forest-agricultural use (Table 2, Figs 2 and 3). Crop fields occupy 37% of the basin and dominate in the northern and central parts of the basin (Fig. 2). The largest concentrations of crop fields are located in the basins of Lake Jorzec (56%) and Lake Głębokie (43%). More than half of the catchment is under intensive agricultural use, of which 50% is occupied by large, over 10-ha, crop fields of the former state farms. These fields form a dense agricultural complex in northern and central parts of the basin. In southern part of the basin, private crop fields are considerably smaller (about 2–4 ha), thus the land is highly fragmented. Their distribution and dispersal match the morainic land configuration.

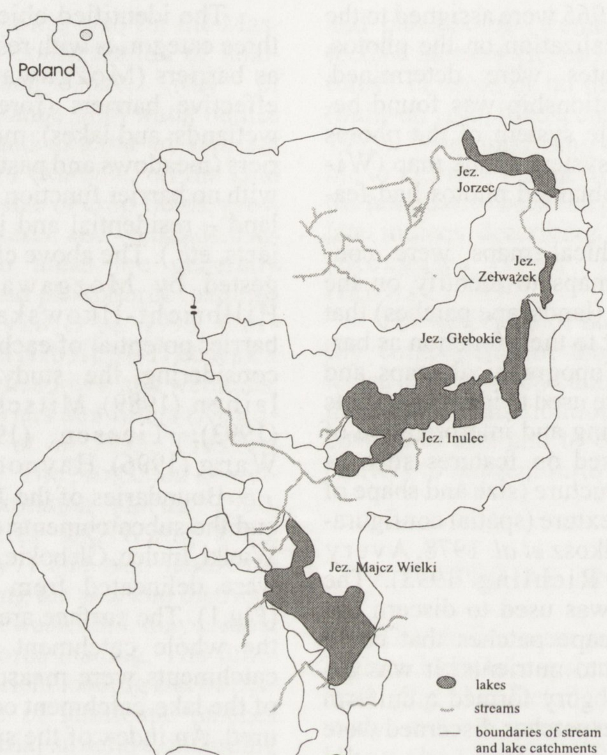

Fig. 1. Outline of the Jorka river catchment basin

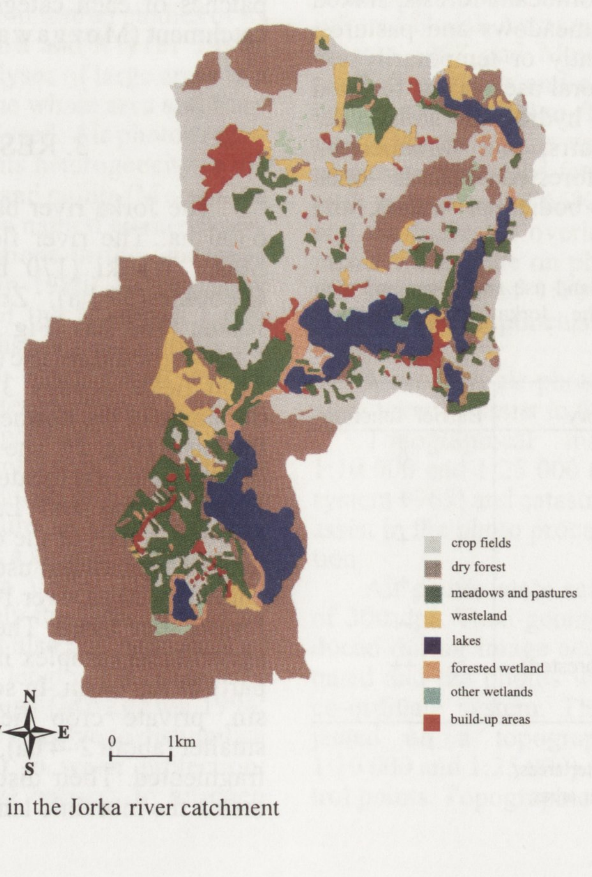

Fig. 2. Land use and cover in the Jorka river catchment

Table 2. Percentage of land use categories in the Jorka river catchment and in subcatchments of lakes

Land use category	Catchment of Jorka river	Subcatchments				
		Majcz	Inulec	Głębokie	Zełwążek	Jorzec
Crop fields	33.6	4.1	41.0	43.0	33.9	56.1
Forest	36.5	64.6	24.3	9.6	9.1	18.5
Meadows and pastures	10.2	13.6	10.9	17.9	5.2	5.1
Wasteland	4.9	1.4	4.9	2.4	4.0	7.0
Lakes	9.6	13.5	13.2	21.1	10.0	2.8
Forested wetlands	1.5	0.9	2.4	3.6	1.0	1.1
Other wetlands (nonforested)	1.1	0.7	0.4	0.5	0.2	4.7
Built-up land	2.7	1.2	2.8	1.9	0.2	4.7

Forests cover 34% of the basin and they are situated mainly in southern and south-western part of the basin, where they form an extensive, dense forest complex, mainly in the Lake Majcz basin, covered with forests in 64%. In northern part, dominated by agriculture, there are only two forest complexes. Forests also surround other lakes (Fig. 2).

Meadows and pastures occupy 10% of the catchment. Most of them are located in its southern part in the Lake Majcz subcatchment, where they occupy 13% of the land (Fig. 2). Typically, they occur in large patches. In the subcatchments of Lakes Inulec and Głębokie, meadows and pastures often border on lake shores.

Wasteland occupies 5% of the whole catchment and most often is associated with agricultural landscape, thus, it is most numerous in northern and central parts (4.9% in the subcatchment of Lake Inulec and 7% in the subcatchment of Lake Jorzec) (Fig. 2). These are primarily areas near large state farms, so they extend over vast, uniform stretches.

Seven larger and a few smaller aggregations of built-up land occupy 2.7% of the Jorka river basin (Fig. 2). These are large villages and small individual farms. The majority of them are located in the subcatchments of Lakes Jorzec and Inulec.

Wet forests and other wetlands occupy about 2% of the whole catchment (Fig. 3). This small cover was a consequence of low precipitation in the summer of 1997 (10 mm in August) and in the spring of 1998 (35 mm in May). That is in months when the air photos were taken. Wetlands primarily extend along lake shores and river banks. Most wet forests occur in the subcatchments of Lakes Inulec and Głębokie.

The subcatchments differ in the proportion of various categories of land use. More than half of the Lake Majcz subcatchment (Fig. 4) is covered with forests, whereas agricultural areas such as crop fields, meadows,

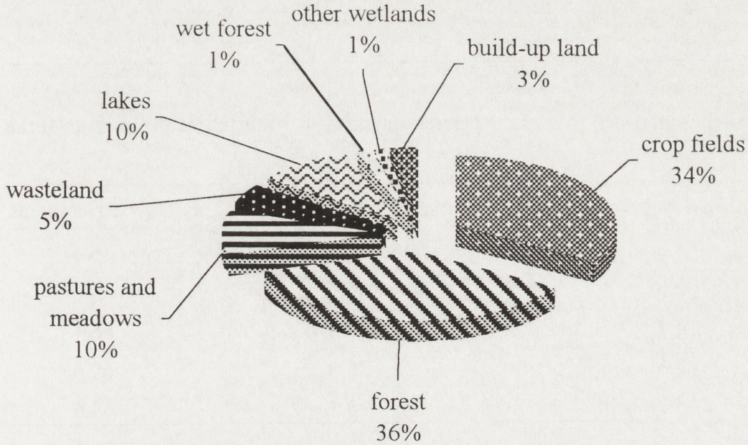

Fig. 3. Percentage of land use catregories in the Jorka river catchment.

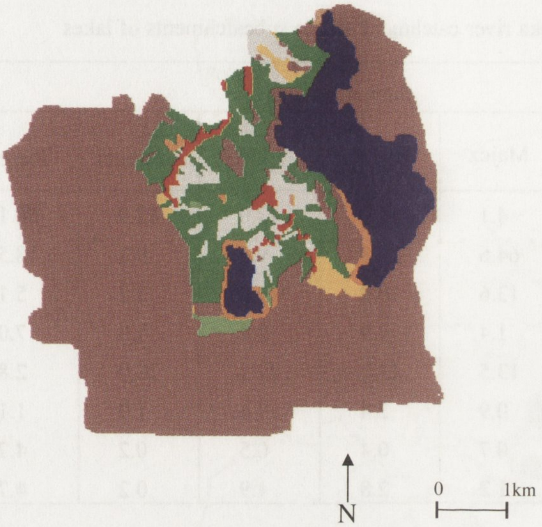

Fig. 4. Land use and cover in the Lake Majcz subcatchment.

and pastures constitute less than one-fifth of its area. The forest forms a large, dense complex in western part, and borders on the eastern lake shore. As many as 72% of the shoreline is connected with areas under forests, including a few percent of wet forests; only 6% of the shoreline is connected with meadows and pastures. Crop fields are interspersed with meadows and pastures, and they occupy a small area of this subcatchment (Table 2). The index of patchiness (forests, crop fields, meadows, and pastures) was low (Table 3). The proportion of highly effective barrier areas was high, that is, 14.3%, whereas moderate effective barriers amounted to almost 80%, and no barrier function areas to 6.1% (Table 4).

The subcatchment of Lake Inulec was predominated by crop fields (41%) (Table 2, Fig. 5), while forests covered 27%, including 2.4% of wet forests. Crop fields were situated in northern and south-eastern part of the subcatchment, where they formed large uniform complexes. Two vast forest stretches were located in the western and southern parts of the subcatchment, and they were not in direct contact with the lake. The western shore (22% of the shoreline) was in contact with wetlands. Crop fields bordered on 18%, built-up land – on 6.6%, meadows and pas-

Table 3. Patchiness indices (number of patches per km^2) of lake subcatchments in river Jorka system (see Figs 1, 2)

Land use category	Subcatchment of lake				
	Majcz	Inulec	Głębokie	Zełwążek	Jorzec
Crop fields	4	4	8	15	3
Forest	2	2	7	6	2
Meadows and pastures	5	3	12	10	1

Table 4. Percentage of landscape patches that differ in their barrier function in subcatchments in river Jorka system (see Figs 1. 2)

Subcatchments of lake	Highly effective barrier areas	Moderate effective barrier areas	No barrier areas
Majcz	14.3	79.6	6.1
Inulec	2.8	40.2	57
Głębokie	4.1	29.8	66.1
Zełwążek	1.6	28.8	69.6
Jorzec	5.7	30.7	63.6

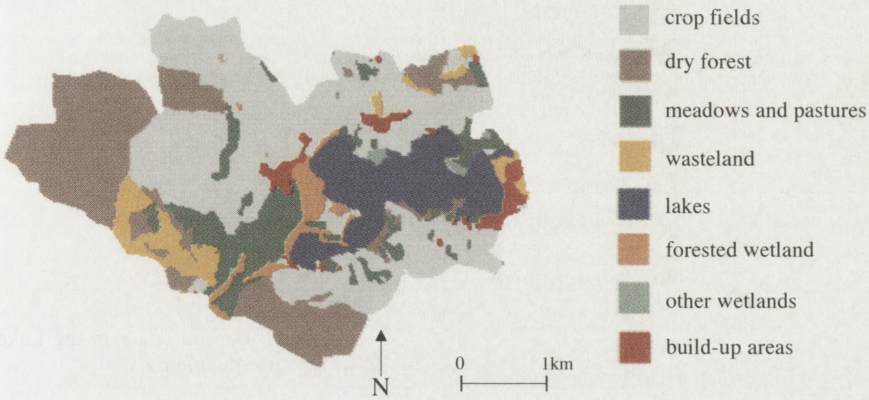

Fig. 5. Land use and cover in the Lake Inulec subcatchment.

tures – on 13% of the shoreline. The index of patchiness for the Lake Inulec subcatchment was similar to that for the Lake Majcz subcatchment. The proportion of highly effective barrier areas was much lower that for the Lake Majcz subcatchment, also the proportion of moderate barriers areas was much lower; the proportion of no barrier function areas was ten times higher (Table 4).

The dominant component of the Lake Głębokie subcatchment was crop fields (Table 2, Fig. 6). They covered 43% of its area, like in the subcatchment of Lake Inulec. Also the proportion of meadows and pastures was high, that is, 18%. Almost the whole shore was surrounded by highly effective barriers. As many as 50% of the shore bordered on forests, 33% on meadows and pastures, and only 8% on crop fields. The patchiness indices were much higher than for the subcatchments of Lakes Majcz and Inulec (Table 3). The subcatchment of Lake Głębokie was much more patchy than the subcatchments of Lakes Majcz and Inulec. The proportion of highly effective barrier areas was very low, and no barrier function areas predominated (Table 4).

The subcatchment of Lake Zełwążek was dominated by crop fields (34%) (Table 2, Fig. 7). Forest (9% of the area) formed a large patch in northern part, and also along the western shore where it occupied half of the shoreline. Crop fields bordered on the shore from the east along one-fourth of the shoreline. Meadows and pastures also occupied one-fourth of the subcatchment area. This subcatchment was characterized by a high patchiness. The patchiness index for crop fields was the highest in the whole Jorka river basin, that is, 15 patches per km^2. It was 10 for meadows and 5.6 for forests (Table 3). The proportion of highly effective barriers areas was the lowest of all subcatchments, whereas the proportion of no barrier function areas was the highest (Table 4).

The subcatchment of Lake Jorzec was of typical agricultural character (Table 2, Fig. 8). Farmland covered half of the subcatchment, and the remaining part was covered with forests (18.5%), wasteland (7%), or meadows and pastures (5.1%) (Table 2). Forests formed three extensive complexes in northern and southern parts, and also along the shores. Built-up land covered almost 5% of the area. Large con-

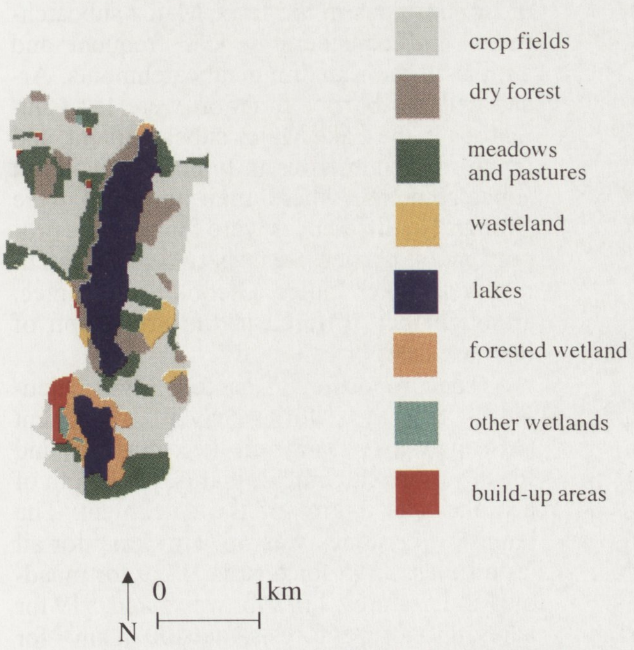

Fig. 6. Land use and cover in the Lake Głębokie subcatchment.

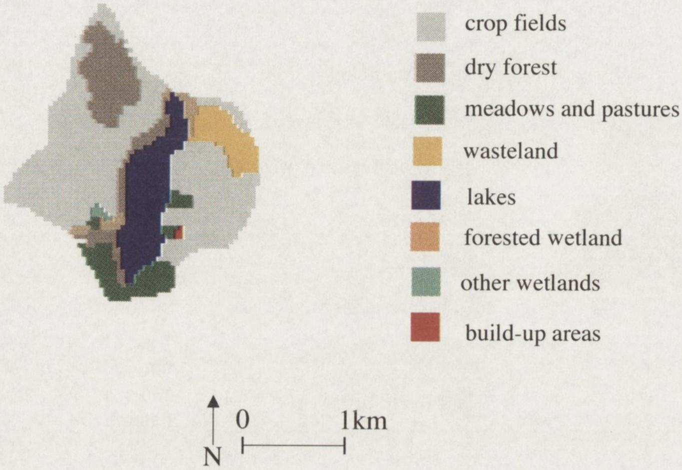

Fig. 7. Land use and cover in the Lake Zelwążek subcatchment.

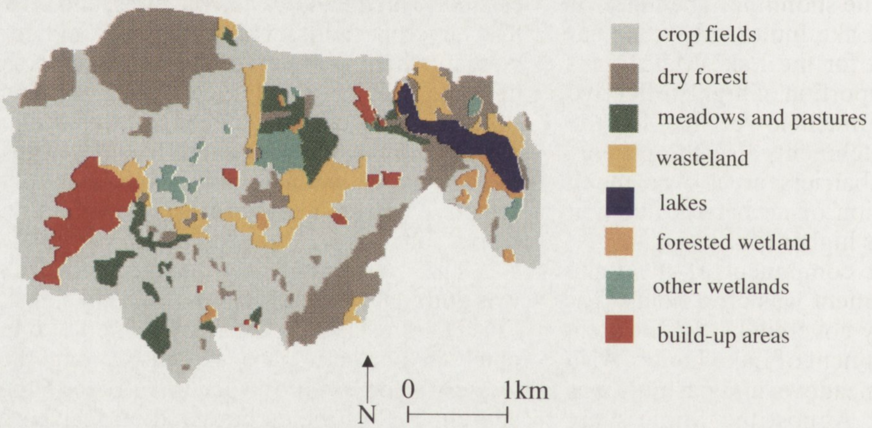

Fig. 8. Land use and cover in the Lake Jorzec subcatchment.

centrations of meadows and pastures were situated in central part of the subcatchment. Crop fields were interspersed with smaller patches of forests, meadows, pastures, and wastelands. Forest and wasteland belts surrounded the shore. Wasteland bordered on the shore along more than half of the shoreline, forest along 38%, and wet forest along 9% of the shoreline. The patchiness index was low for crop fields because the fields of the former state farms were very extensive (Table 3). For the same reason, also the patchiness of forests was low (Table 3). The proportion of areas that differed with respect to their function as barriers was similar to that in the Lake Głębokie subcatchment, the areas with no barrier function being dominant (Table 4).

The proportion of areas that differed in their function as barriers was not the same in various subcatchments (Table 4). The proportion of areas functioning as highly effective barriers was similar (except Lake Majcz) in all subcatchments, but the proportion of areas representing moderate barriers or no barriers varied from subcatchment to subcatchment. Moderate barrier areas were most numerous in the Lake Majcz subcatchment, and considerably less frequent and similar in the remaining subcatchments. Areas with no barrier function were least numerous in the Lake Majcz subcatchment, and much more numerous in typical agricultural subcatchments, where their numbers were similar. No differences were found in the proportion of barrier areas between subcatchments of Lakes Inulec, Głębokie and Jorzec, although they differed in the proportion of land use categories.

The proportion of ecotones was calculated in the Jorka river catchment (Mozgawa 1995) for all the categories and for the entire catchment, that is, the length of ecotones per 1 km^2 of the catchment. The length of ecotones was 4671 m km^{-2} for all crop fields, 3345 for forests, 3229 for meadows and pastures, 1192 for wasteland, 919 for lakes, 830 for wet forests, and 400 m km^{-2} for other wetlands.

Table 5. Proportions of land use categories in three groups areas with different agricultural impact in river Jorka basin

Land use category	agricultural impact		
	low	moderate	high
crop fields	4.1	41.4	56.0
forest	64.6	21.5	18.3
meadows and pastures	13.6	12.3	5.3
wasteland	1.4	4.4	7.0
forested wetland	0.9	2.7	1.1
other wetlands (nonforested)	0.7	0.4	4.5
built-up land	1.2	2.6	4.5

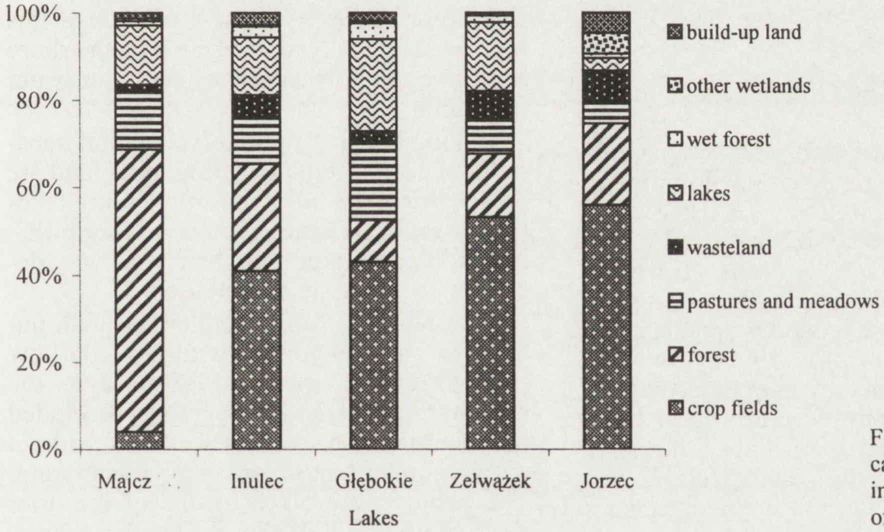

Fig. 9. Proportion of categories of land use in lake subcatchments of river Jorka system.

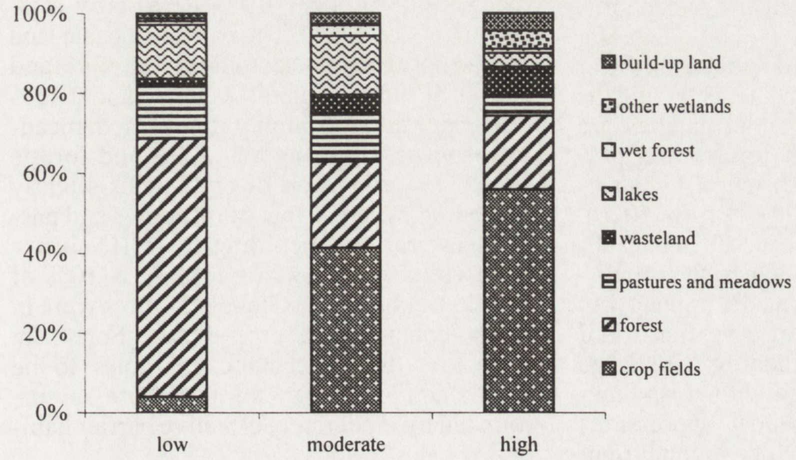

Fig. 10. Proportion of categories of land use in lake subcatchments with high, moderate and low agricultural impact.

To analyse the input of nitrogen and phosphorus from the catchment to the lakes, the entire catchment of the Jorka river was divided into three partial catchments that differed in terms of the agricultural inflow (Table 5). The criterion was the proportion of agricultural land, forests, meadows and pastures in the catchment (Fig. 9). The first group, Lake Majcz catchment, was subjected to a low agricultural impact, with 41% of agricultural land, 21% of forests, and 12% of meadows and pastures. The catchments of Lakes Zełwążek and Jorzec were under high impact of agriculture, with 56% cropland, 18% forests, and 5% meadows and pastures (Fig. 10).

4. DISCUSSION

The study area was characterized by a high patchiness, determined primarily by land configuration (Bajkiewicz-Grabowska 1985, Kloss and Wilpiszewska 1985, Hillbricht-Ilkowska 1981). The hilly lakeland landscape imposes its patchy use and management (Hillbricht-Ilkowska 1999). However, this area is dominated by crop fields and forests. They form extensive, uniform patches of cropland in northern part and of forests in southern part of the catchment. Consequently, ecotones are less important than in other categories of use.

A large number of patches functioning as weak barrier areas or moderately effective barrier areas, such as crop fields or urban areas, used for many years in the same way (Bajkiewicz-Grabowska 1985) may be indicative of a large nitrogen and phosphorus input from the catchment to water bodies. But the least agriculturally used subcatchment of Lake Majcz has also few areas acting as highly effective barriers; most patches are moderate barriers such as forests and pastures. Their alternate distribution enhances reduction of nutrient input (Rybak 2000). A different situation was observed in the subcatchment of Lake Jorzec, where the proportion of effective barriers was the highest, but a very high contribution of crop fields and urban/urbanized areas extending over large areas, often not interspersed with areas functioning as barriers (wetlands, depressions without outflow), accounts for a high nutrient inflow from the catchment (Rybak 2000). It is worth noting that meadows and pastures, occupying only 10% of the total catchment, have long ecotones, and for this reason they are almost as effective as forests, whose contribution is almost three times higher. Vast stretches of crop fields in northern part account for fragmentation of other categories in this area, although the patchiness index of different categories is not high. High fragmentation of landscape patches is determined by the relief of this mosaic land (Hillbricht-Ilkowska 1999). The highest patchiness occurred in the subcatchments of Lakes Głębokie and Zełwążek. The proportion of areas serving as highly effective barriers such as wetlands (wet meadows, wet forests) or pastures was low; patches of this kind were typically located far from the shore and were not sufficiently effective in water protection.

Wide belts of riparian vegetation separating the lake from the surrounding land are best barriers to nutrient inflow into lakes (Hillbricht-Ilkowska 1999, Rzepecki, 2002). The width of these belts may vary depending on the type of land use.

Morainic landforms are dotted with numerous depressions without outflow (Hillbricht-Ilkowska 1999). But the resolution of aerial photographs precluded the identification of most wetlands without outflow, important to landscape functioning. The photos were taken in one of the drier years (Rybak 2000), thus the number of wetlands may be underestimated relative to dry land. In normal, moderately wet months, wetlands may occupy much larger areas.

The use of the Jorka river catchment shows a kind of stability as compared with the period of 1977–1979 (Bajkiewicz-Grabowska 1985). The pattern of basic land use did not change. According to Traczyk and Kloss (1985), farmland occupied about 45% of the area and was highly fragmented, meadows and pastures covered 23%, and forests 17%. The proportion of crop fields slightly decreased, whereas that of meadows and pastures increased. According to Hillbricht-Ilkowska and Ławacz (1983), 8–10% of the Lakes Inulec and Głębokie shores were in direct contact with crop fields. For Lake Głębokie, this percentage continues to be small, and over 50% of the shore is surrounded by moderately effective barrier habitats.

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5. SUMMARY

The objective of the study was to identify components of the landscape of a selected lakeland catchment basin (river Jorka catchment, Masurian Lakeland, Poland) (Fig. 1), to assess their size and distribution with respect to their cover and use, and to evaluate their role as barriers to nutrient inflow into lakes (Fig. 2). Aerial photographs (1:10 000) from 1997 and 1998 were applied to identify the use and cover of catchment. The air photos and topographical maps were used to identify objects (landscape patches) that differed with respect to their function as barriers to nutrients. Each landscape patch was allocated to one of the eight categories of land cover and use: crop fields, forests (forests on mineral soils, oak-hornbeam forests, mixed coniferous forests), meadows and pastures, wasteland (permanently or temporarily excluded from agricultural use), lakes, wet forests (forests on hydrogenic soils, alder swamps, riparian carrs, and shrubberies), other wetlands (open wetlands, mid-field bodies of water), and built-up land (Figs 3, 4, 5, 6, 7, 8). The identified objects were assigned to three categories with respect to their function as barriers (Figs 9, 10): highly effective barriers (forested and non-forest wetlands, and lakes – 6% of Jorka river catchment); moderate effective barriers (forest, meadows and pastures, wasteland – 42%); and with no barrier function (arable land, built-up land – residential and industrial, tourist objects, etc. – 52%).

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